IoT Product Design and Rapid Prototyping

Brian Rashap

January 2023

Class Logistics

Brian Rashap, Ph.D.

- Proud husband of Krista and father of Shelby (25) and Ethan (21)
- Electrical Engineer (Michigan) with 25 years industrial experience (Intel)
- Hobbies: running, cycling, reading, spending time with family

Edward (EJ) Ishman

- Loving father of two exceptional children Ziona (7) and Ivee (5)
- 4 years as an Aerospace Maintenance Journeyman (Crew Chief) in the United States Air Force
- CNM Ingenuity IoT Bootcamp graduate (Cohort 6)
- Hobbies: Photography, Live entertainment, exploring the outdoors, thrifting.

Reed Searle

- Recently retired helicopter pilot who flew ambulance and aerial firefighting missions
- Aerospace (Embry-Riddle) / Electrical Engineer (ASU)
- CNM Ingenuity IoT Bootcamp graduate (Cohort 7), patented one of his capstone projects

Introductions

INTRODUCTIONS

Class Rules

- Respect each other. Help each other.
- Ask questions.
- Be on time (let us know via Slack if you won't be here)
- Keep your workspace and the classroom neat and tidy.
- If you are struggling, let me, Susan, or Esteban know. We are here to HELP!
- Class hours
  - Mon-Th: 8am to 5pm [1]
  - Friday: 8am to 3pm [2]
  - Lunch Break: 1 hour near noon. Maybe combined with work time.
  - Please respect Brian and EJ's lunch break as well.

[1] Doors open at 7:50, please be in your seats ready to learn by 8:00

[2] Occasionally on Friday there will be optional activities from 3 to 5

Grading

Assignments total 1000 points. To graduate, you need to earn at least:

- 750 total points
- 200 points (80%) on the Capstone.
- 65 points (65%) on Quizzes, the two Midterms, and Solidworks.

Point distribution

1. IoT assignments + Lab Notebooks: 300 points [3]
2. 3D modeling (Solidworks) assignments: 100 points
3. Weekly quizzes: 100 points
4. Midterm Projects: Smart Room Controller/Plant Watering System: 100 points each (200 total)
5. Team Capstone Project: 250 points
6. Professional Development: 50 points

[3] All coding assignments must follow style-guide

Credit for Prior Learning (CPL)

Approved for CPL	
CIS 1605	Internet of Things
CIS 1275	Introduction to C++
BCIS 1110	Fundamentals of Information Literacy and Systems
BUSA 1130	Business Professionalism
BUSA 1198	Project Management Fundamentals
CSIS 1151	Intro to Programming for Non-Majors of CS*

* CSIS 1151 credit requires appropriate math prerequisites

Introduction

"THE CHANGING OF THE PASSWORDS HAS BECOME A DAILY EVENT."

Pizza Finder

https://www.youtube.com/watch?v=aY0OtOy6lcE&t=6s

Let's Build Something

Oscillator: Flip Flop

Components:

- breadboard
- light emitting diode (LED)
- wires
- resistors
- capacitors
- transistors
- battery charge circuit

Evolution of Industry

Components of Industry 4.0

What Is the Internet of Things

IoT 2025

Home
Chore automation and security
$200B–350B
Vehicles
Autonomous vehicles and condition-based maintenance
$210B–740B
Offices
Security and energy
$70B–150B
9 settings
gave us a cross-sector view of a total potential impact of
$3.9 trillion–11.1 trillion per year in 2025
Cities
Public health and transportation
$930B–1.7T
Factories
Operations and equipment optimization
$1.2T–3.7T
SHOP
Outside
Logistics and navigation
$560B–850B
Human
Health and fitness
$170B–1.6T
Worksites
Operations optimization/ health and safety
$160B–930B
Retail environments
Automated checkout
$410B–1.2T

Smart Facilities

Healthcare 2025

Smart World

Libelium Smart World
Air Pollution
Control of CO_2 emissions of factories, pollution emitted by cars and toxic gases generated in farms.
Forest Fire Detection
Monitoring of combustion gases and preemptive fire conditions to define alert zones.
Wine Quality Enhancing
Monitoring soil moisture and trunk diameter in vineyards to control the amount of sugar in grapes and grapevine health.
Offspring Care
Control of growing conditions of the offspring in animal farms to ensure its survival and health.
Sportsmen Care
Vital signs monitoring in high performance centers and fields.
Structural Health
Monitoring of vibrations and material conditions in buildings, bridges and historical monuments.
Quality of Shipment Conditions
Monitoring of vibrations, strokes, container openings or cold chain maintenance for insurance purposes.
Smartphones Detection
Detect iPhone and Android devices and in general any device which works with Wifi or Bluetooth interfaces.
Perimeter Access Control
Access control to restricted areas and detection of people in non-authorized areas.
Radiation Levels
Distributed measurement of radiation levels in nuclear power stations surroundings to generate leakage alerts.
Electromagnetic Levels
Measurement of the energy radiated by cell stations and WiFi routers.
Traffic Congestion
Monitoring of vehicles and pedestrian affluence to optimize driving and walking routes.
Smart Roads
Warning messages and diversions according to climate conditions and unexpected events like accidents or traffic jams.
Smart Lighting
Intelligent and weather adaptive lighting in street lights.
Intelligent Shopping
Getting advices in the point of sale according to customer habits, preferences, presence of allergic components for them or expiring dates.
Noise Urban Maps
Sound monitoring in bar areas and centric zones in real time.
Water Leakages
Detection of liquid presence outside tanks and pressure variations along pipes.
Vehicle Auto-diagnosis
Information collection from CanBus to send real time alarms to emergencies or provide advice to drivers.
Item Location
Search of individual items in big surfaces like warehouses or harbours.
Waste Management
Detection of rubbish levels in containers to optimize the trash collection routes.
Smart Parking
Monitoring of parking spaces availability in the city.
Water Quality
Study of water suitability in rivers and the sea for fauna and eligibility for drinkable use.
Golf Courses
Selective irrigation in dry zones to reduce the water resources required in the green.
libelium
www.libelium.com

And Out of This World

IoT and Data Science

How Big Will IoT Be

How ubiquitous is the Internet of Things?

- There are approximately 31 billion IoT devices today.
- 127 new IoT devices are connected to the internet every SECOND.
- This morning, 1,828,800 IoT devices will be added to the internet.

Let's Begin Our Journey

Computer Languages

Why C++

Features of C++
Simple
Portability
Compiler-Based
Mid-Level Programming
Dynamic Memory Allocation
Rich Library
Recursion
Case Sensitive
Fast
Object-Oriented Programming
www.educba.com

Operating Systems

CLI vs GUI

[root@localhost ~]# cd /var
[root@localhost var]# ls -la
total 72
drwxr-xr-x. 18 root root 4096 Jul 30 22:43 .
drwxr-xr-x. 23 root root 4096 Sep 14 20:42 ..
drwxr-xr-x. 2 root root 4096 May 14 00:15 account
drwxr-xr-x. 11 root root 4096 Jul 31 22:26 cache
drwxr-xr-x. 3 root root 4096 May 18 16:03 db
drwxr-xr-x. 3 root root 4096 May 18 16:03 empty
drwxr-xr-x. 2 root root 4096 May 18 16:03 games
drwxrwx--T. 2 root gdm 4096 Jun 2 18:39
drwxr-xr-x. 38 root root 4096 May 18 16:03
drwxr-xr-x. 2 root root 4096 May 18 16:03
drwxr-xr-x. 2 root root 4096 May 18 16:03
drwxr-xr-x. 2 root root 4096 Jul 1 22:11
lrwxrwxrwx. 1 root root 6 May 14 00:12 run
drwxr-xr-x. 14 root root 4096 May 18 16:03 spool
drwxrwxrwt. 4 root root 4096 Sep 12 23:50 tmp
drwxr-xr-x. 2 root root 4096 May 18 16:03 yp
[root@localhost var]# yum search wiki
plugins: langpacks, presto, refresh-packagekit,
73% [
VS
Start

Windows Users - We Need Git Bash

Windows:

- https://git-scm.com/download/win

Mac (from Terminal)

```
# install homebrew
/bin/bash -c "$(curl -fsSL https://raw.githubusercontent.com/Homebrew/install/HEAD/install.sh)"

# might be necessary on M1/M2 Macs
eval $(/opt/homebrew/bin/brew shellenv)

# install git
brew install git
```

Linux (from Terminal)

```
sudo apt-get install git-all
```

Command Line Interface - Basic Navigation

The Command Line Interface (CLI) will allow us to directly navigate the computers operating system. We will use:

- macOS or Linux: Terminal
- Windows: PowerShell or Git Bash (we will use Git Bash)

The following commands will work on all three systems, except where noted below. macOS and Linux are case-sensitive, Windows is not.

- pwd: Show the present working directory.
- ls: To get the list of all the files or folders.
- cd: Used to change the directory.
- du: Show disk usage. (not available in PowerShell).
- man: Used to show the manual of any command.

Command Line Interface - File and Directory Manipulation

- mkdir: Used to create a directory if it does not already exist. It accepts directory name as input parameter.
- rmdir: Used to delete a directory if it is empty.
- cp: This command will copy the files and directories from source path to destination path. It can copy a file/directory with a new name to the destination path. It accepts source file/directory and destination file/directory.
- mv: Used to move files or directories. This command is similar to the cp command but it deletes a copy of the file or directory from the source path.
- rm: Used to remove files or directories.
- touch: Used to create or update a file. (PowerShell New-Item).

Command Line Interface - Displaying the file contents

- cat: It is generally used to concatenate files. It gives the output on the standard output.
- more: It is a filter for paging through text one screenful at a time.

The below commands are not available in PowerShell:

- less: Used for viewing files instead of opening the file. Similar to the "more" command but it allows backward as well as forward movement.
- head: Used to print the first N lines of a file. It accepts N as input and the default value of N is 10.
- tail: Used to print the last N-1 lines of a file. It accepts N as input and the default value of N is 10.

On all systems, commands can be "piped" together: ls | more < *file* >

GitHub - Part 1

Git and GitHub: Your Version Control Friends

What is a version control system?

Version Control Systems (VCS) record changes made to files so that you can

- compare and track changes over time
- revert single files to a previous state
- revert an entire project to an earlier version

Git is a VCS, or Version Control System.
It is similar to Backup on Windows or Time Machine on the Mac.

Installing Git

Windows:

- https://git-scm.com/download/win

Mac

```
# install homebrew
/bin/bash -c "$(curl -fsSL https://raw.githubusercontent.com/Homebrew/install/HEAD/install.sh)"

# might be necessary on M1/M2 Macs
eval $(/opt/homebrew/bin/brew shellenv)

# install git
brew install git
```

Linux

```
sudo apt-get install git-all
```

Git vs. GitHub

Commit vs. Push

To save files to your **LOCAL** repository. use the *commit* command. The file is given a timestamp and a unique commit number that is the file version.

→ git commit

To save a file to your **REMOTE** GitHub repository, use the *push* command.

→ git push

Remember to Push your files in order to save from data loss and to ensure your work is available for collaboration.

When should you commit and push your work?

When to commit? **OFTEN!**

- Any time you finish a task where you want to save or retain a version.

When to push? **OFTEN!**

- Any time you have finished a task, milestone, or significant project.
- At the end of each work session
  - Before you take a break
  - Before a meeting
  - Before lunch
  - Before you go offline for the day

Use Professional Naming

Getting a GitHub account

If you do not already have a GitHub account, you will want to create one.

1. Go to `https://github.com`
2. Click Sign Up.
3. Type a unique username and password for your account.
   - *Note: you should consider a user name that is professional if you plan to share your GitHub account with prospective employers as part of your work portfolio.*
4. Complete the sign up process and Create Account.

GitHub Authentication: Using HTTPS and PAT

Effective August 2021, account passwords will no longer be allowed for command line GitHub access. Instead, you must create a Personal Access Token (PAT) to use in place of a less secure password.

To create a PAT:

1. Login to your GitHub account.
2. Click your account icon.
3. Click the Settings menu option.
4. Click Developer Settings.
5. Click Personal access tokens.
6. Generate a new token for GitHub Command Line Access.
7. Check the repo option.
8. Click Generate Token.

Now when you login to GitHub on the command line, use your PAT rather than your password to access your account.

GitHub: Cloning and Pulling Code

To get an existing GitHub repository, you will clone it to your local system.

git clone <URL of repository>

Let's get the Class Slide now, from your IoT directory:

```
1 git clone https://github.com/ddc-iot/class_materials
```

To get updates from a GitHub repository after you have already cloned it to your local system, you will pull the code.

git pull

Note: make sure you are in the repository folder before doing a git pull.

GitHub: Getting Assignments

ddc-iot-classroom-2

Accept the assignment — L01_HelloWorld

Once you accept this assignment, you will be granted access to the `l01-helloworld-brashap` repository in the ddc-iot organization on GitHub.

Accept this assignment

You're ready to go!

You accepted the assignment, **L01_HelloWorld**.

Your assignment repository has been created:

https://github.com/ddc-iot/l01-helloworld-brashap

```
brian:~$ cd Documents/
brian:Documents$ mkdir IoT
brian:Documents$ cd IoT
brian:IoT$ git clone https://github.com/ddc-iot/L01_helloWorld-brashap
Cloning into 'L01_helloWorld'...
Username for 'https://github.com': brashap
Password for 'https://brashap@github.com':
  remote: Enumerating objects: 4, done.
  remote: Counting objects: 100% (4/4), done.
  remote: Compressing objects: 100% (3/3), done.
  remote: Total 4 (delta 0), reused 4 (delta 0), pack-reused 0
  Unpacking objects: 100% (4/4), 321 bytes | 53.00 KiB/s, done.
```

GitHub: Cheatsheet. Memorize this!

```
// In PowerShell go to ./Documents/IoT
// Get a repository that already exists and pull
   it into your local machine
  git clone <URL of repository>

// Send your changes up to the repository
  git add . //adds all changed files
  git commit -m "some comment"
  git push  //send your changes to the cloud

// The first time you use git, you may get asked
   to enter your GIT username
git config --global user.email "you@example.com"

// From the repository directory, get updates
  git pull
```

Solidworks - Windows Users

To install Solidworks (Windows only), go to
`http://www.SolidWorks.com/SEK`

- Enter your contact information.
- Check the radio button "Yes" under "I already have a Serial Number that starts with 9020".
- Select the version: 2023 SP2.1 and click Request Download.
- On the next page, Accept the agreement and continue.
- On the final page, click the Download button to download the SolidWorks Installation Manager.
- Unzip the files to launch the Installation.
- Select the option for Individual/On this machine.
- Install using the following serial number provided by your instructor.

macOS and Linux users will use onShape:
`https://www.onshape.com/en/education/`

Other Software

1. Fritzing
   - Installer is in Brightspace: Module 02 HelloLED
2. Bambu Studio
   - `https://bambulab.com/en/download/studio`
3. Adobe Illustrator
   - `https://www.adobe.com/creativecloud.html`
4. KiCad
   - https://www.kicad.org/download/
5. Drawio
   - `https://app.diagrams.net/`
6. Bookmark: `https://www.desmos.com/`

Particle Photon2

Our Microcontroller

Smart Room Controller

Smart Room Controller Schematic

Particle Photon2

Peripheral Type	Qty	Input(I) / Output(O)
Digital	20	I/O
Analog (ADC)	6	I
SPI	2	I/O
I2C	1	I/O
UART	3	I/O
USB	1	I/O
PWM	5	O

Particle Photon2 Block Diagram

Features

- 802.11a/b/g/n Wi-Fi, 2.4 GHz and 5 GHz
  - Integrated PCB antenna
  - Integrated U.FL connector for external antenna
  - Integrated RF switch
- BLE 5 using same antenna as Wi-Fi
- Realtek RTL8721DM MCU
  - ARM Cortex M33 CPU, 200 MHz
- 2048 KB (2 MB) user application maximum size
- 3072 KB (3 MB) of RAM available to user applications
- 2 MB flash file system
- FCC, IC, and CE certified

Photon2 Pinout

Particle Cousins

You may see the Particle Argon on some wiring diagrams in later slides. In those cases, the Argon and the Photon2 are fully interchangeable.

Platform as a Service

Please Do Not Skip Ahead During Setup

If you have a Mac M1/M2 (Apple Silicon)

Terminal needs to be "Open using Rosetta" option:

https://www.courier.com/blog/tips-and-tricks-to-setup-your-apple-m1-for-development/

Installing Particle CLI

Windows (After download, right click and Run as Administrator):

- https://docs.particle.io/tutorials/developer-tools/cli/

Mac

```
# install the CLI
bash <( curl -sL https://particle.io/install-cli )

# install the DFU-util, a utility program for programming devices over USB
brew install dfu-util

# either or both of the following might be necessary on M1/M2 Macs
eval $(/opt/homebrew/bin/brew shellenv)   # if brew doesn't work
arch -arm64 brew install dfu-util         # if architecture error
```

Linux

```
# install the CLI
bash <( curl -sL https://particle.io/install-cli )

# install the DFU-util, a utility program for programming devices over USB
sudo apt-get install dfu-util
```

- Test that the Particle CLI installed correctly by going to PowerShell or Terminal and type particle.

Particle Software - Visual Studio Code

1. Create Particle login: `https://login.particle.io/signup`
2. Download Particle Workbench / Visual Studio Code `https://docs.particle.io/quickstart/workbench/`.
   - Select all default values during install.
   - **Do NOT install Azure IoT.**
   - After it is installed, when you launch it, it may ask you to Install Dependencies. If so, select yes.
3. If Particle Workbench doesn't install correctly
   - Install VSCode
   - Manually install the Workbench extension from within VSCode

Particle Setup

1. Plug the Photon2 into a USB port. It should begin blinking blue.
2. Open PowerShell or Terminal.
3. Login into your Particle Account.

```
particle login
```

4. Ensure you have the latest Particle CLI.

```
particle update-cli
```

5. Put the Photon2 in DFU mode (blinking yellow) by holding down MODE. Tap RESET and continue to hold down MODE. The status LED will blink magenta (red and blue at the same time), then yellow. Release when it is blinking yellow.

Updating your Photon2 to latest Device OS

1. Update the device by running the following two commands. If the device goes out of blinking yellow after the first command, put it back into DFU mode. See Note [4].

```
particle update
particle flash --usb tinker
```

2. When the command reports Flash success!, reset the Argon. It should go back into listening mode (blinking dark blue).
3. Verify that the update worked by running the following command:

```
particle serial identify

Your device id is e00fce681ffffffffc08949b
Your system firmware version is 1.5.2
```

[4] particle flash –usb tinker can be used for device troubleshooting

Setting Up WiFi

- Set your Particle device into Listening Mode by holding the MODE button for three seconds, until the RGB LED begins blinking blue.
- Execute the command: particle serial wifi

```
brian:~$ particle serial wifi
? Should I scan for nearby Wi-Fi networks? No
? SSID DDCIOT
? Security Type WPA2
? Cipher Type AES+TKIP
? Wi-Fi Password ddcIOT2020
Done! Your device should now restart.
```

After setting, your Particle device should go through the normal sequence of blinking green, blinking cyan (light blue), fast blinking cyan, and breathing cyan.

Claim Your Device

1. Claim the device to your account. This can only be done if it's breathing cyan. Replace e00fce681ffffffffc08949b with the device ID you got earlier from particle serial identify. Then, rename it to the name of your choice.

```
particle device add e00fce681ffffffffc08949b
particle device rename e00fce681ffffffffc08949b
    myPhoton2
```

2. Ensure that your setup flag is marked as done.

```
particle usb setup-done
```

3. You have successfully set up your Photon2!

Useful Particle CLI Commands

1. Enter DFU mode from the CLI.

```
particle usb dfu
```

2. If the Argon won't enter DFU mode or is otherwise acting strangely, restore the base firmware.

```
particle flash --usb tinker
```

3. Get a list of your Particle devices and their connection status.

```
particle list
```

4. Search for available libraries.

```
particle library search <search term>
```

5. Link for the Particle Setup procedures: Particle Setup via CLI

Particle Troubleshooting

1. Enter DFU mode from the CLI.

```
particle usb configure
```

Particle LED Modes

Mode	LED Status
Connected	Breathing Cyan
OTA Firmware Update	Blinking Magenta (red and blue together)
Looking for Internet	Blinking Green
Connecting to Cloud	Rapid Blinking Cyan
Listening Mode	Blinking Blue
Network Reset	Rapid Blinking Blue
WiFi Off	Breathing White
Safe Mode	Breathing Magenta (red and blue together)
DFU (Device Firmware Upgrade	Blinking Yellow
Restore Factory Firmware	Rapid Blinking Yellow
Factory Reset	Rapid Blinking White
Decryption Error	Blinking Cyan followed by 1 Orange Blink
No Internet	Blinking Cyan followed by 2 Orange Blink
No Particle Cloud	Blinking Cyan followed by 3 Orange Blink
Authentication Error	Blinking Cyan followed by 1 Magenta Blink
Handshake Error	Blinking Cyan followed by 1 Red Blink
Decryption Error	Blinking Cyan followed by 1 Orange Blink
SOS - Firmware Crash	Blinking Red - 3 short, 3 long, 3 short, error code

Directory Structure - VERY IMPORTANT

Directory Structure - VERY IMPORTANT

- The .vscode directory contains your project-specific settings.
- The src directory contains your source file. The .ino file is transformed into a .cpp before compiling.
- Not pictured here is the lib directory, at the same level as src. This contains the source to libraries that you have included.
- The target directory contains local build output
- The *.bin file is the result of a cloud compile for this project.
- The project.properties file specifies all of the libraries that this project uses.
- README.md is where you could put documentation for your project.

Command Palette - Ctrl-Shift-P

Improve Compile Time

Anti-virus programs scan everything that VSCode is doing. This leads to long compile times. To reduce the compile times, you can exclude your particle code from real-time virus scans.

Windows Defender

Go to Start > Settings > Update & Security > Windows Security > Virus & threat protection. Under Virus & threat protection settings, select Manage settings, and then under Exclusions, select Add or remove exclusions. Select Add an exclusion, and then select from files, folders, file types, or process.

Bitdefender

How to exclude files and folders from Bitdefender Antivirus scan

1. Click Protection on the navigation menu on the Bitdefender interface.
2. In the ANTIVIRUS pane, click Open.
3. In the Settings window, click Manage Exceptions.
4. Click +Add an Exception.

AVG

To set a global exception:

1. Open AVG AntiVirus and go to ☰ Menu ‣ Settings.
2. Select General ‣ Exceptions, then click Add exception.
3. Add an exception in one of the following ways: Type the specific file/folder path or URL into the text box, then click Add exception.

McAfee

1. Open your McAfee security software.
2. Click PC Security.
3. Click Real-Time Scanning .
4. Click Excluded Files .
5. Click Add file .
6. Browse to, and select, the file that you want to exclude from Real-Time scanning.

Module 1 - HelloWorld

Argon on Breadboard

Horizontal Rows

Vertical Columns

Basic Structure of IoT Program

```
// the "header" is used for GLOBALS

void setup() {
  // code in setup() runs once
  // it is used to initialize objects,
  // begin processes, and set variables
  pinMode(D7, OUTPUT);  //set Pin D7 as an Output
}

void loop() {
  // functionality of your code
  // this loops indefinitely
}
```

Class Assignments

1. Lab Notebook - flow chart
2. Lab Notebook - schematic
3. Fritzing breadboad layout
4. IoT code with comments

```
/*
 * Project:     Title of Project
 * Description: Description of Project
 * Author:      Your Name
 * Date:        Today's Date
 */

// Single Line Comments
```

Hello World in some of the 603+ Coding Languages

Fortran

```
C     Hello World in Fortran

      PROGRAM HELLO
      WRITE (*,100)
      STOP
  100 FORMAT (' Hello World! ' /)
      END
```

C (K&R)

```
/* Hello World in C, K&R-style */

main()
{
  puts("Hello World!");
  return 0;
}
```

Python 2

```
# Hello world in Python 2

print "Hello World"
```

Assembler (Intel)

```
; Hello World for Intel Assembler (MSDOS)

mov ax,cs
mov ds,ax
mov ah,9
mov dx, offset Hello
int 21h
xor ax,ax
int 21h

Hello:
  db "Hello World!",13,10,"$"
```

Powershell

```
# Hello World in Microsoft Powershell

'Hello World!'
```

LabVIEW

LaTeX

```
% Hello World! in LaTeX
\documentclass{article}
\begin{document}
Hello World!
\end{document}
```

Unix Shell

```
# Hello world for the Unix shells (sh, ksh, csh, zsh, bash, fish, xonsh, ...)

echo Hello World
```

Lisp-Emacs

```
;;; Hello World in Emacs Lisp.

(defun hello-world()
  "Display the string hello world."
  (interactive)
  (message "hello world"))
```

BASIC

```
10 REM Hello World in BASIC
20 PRINT "Hello World!"
```

C++

```
// Hello World in C++ (pre-ISO)

#include <iostream.h>

main()
{
    cout << "Hello World!" << endl;
    return 0;
}
```

Perl

```
# Hello world in perl

print "Hello World!\n";
```

Python 3

```
# Hello world in Python 3

print("Hello World")
```

Pascal

```
{Hello world in Pascal}

program HelloWorld(output);
begin
  WriteLn('Hello World!');
end.
```

MATLAB

```
% Hello World in MATLAB.

disp('Hello World');
```

HTML

```
<HTML>
<!-- Hello World in HTML -->
<HEAD>
<TITLE>Hello World!</TITLE>
</HEAD>
<BODY>
Hello World!
</BODY>
</HTML>
```

Postscript

```
% Hello World in Postscript
%!PS
/Palatino-Roman findfont
100 scalefont
setfont
100 100 moveto
(Hello World!) show
showpage
```

Assignment L01_01_HelloWorld

We will write our first program together as a class, using:

- pinMode(pin,mode)
- digitalWrite(pin,state)
- delay(delay_time)

How fast can you make it blink and still see it blinking?

Solidworks

To install Solidworks (Windows only), go to `http://www.SolidWorks.com/SEK`

- Enter your contact information.
- Check the radio button "Yes" under "I already have a Serial Number that starts with 9020".
- Select the version and click Request Download.
- On the next page, Accept the agreement and continue.
- On the final page, click the Download button to download the SolidWorks Installation Manager.
- Unzip the files to launch the Installation.
- Select the option for Individual/On this machine.
- Install using the following serial number provided by your instructor.

macOS and Linux users will use onShape:
`https://www.onshape.com/en/education/`

Module 2 - HelloLED

Rubber Ducking - An Odd but Brilliant Tool

Rubber ducking is simply a method of debugging code. Programmers carry around a rubber duck with them, When they get stuck, they explain their code line-by-line to the rubber duck.

Introduction to Electrical Circuits

Energy

- Kinetic Energy - energy of motion
- Potential Energy - energy stored in an object

Electrical Circuit Terms

Voltage is **electric potential energy per unit charge** (V = J/C)

The Sub-atomic Particles			
Relative size	Name	Mass (Kg)	Charge (C)
	Proton	1.67×10^{-27}	$+1.602 \times 10^{-19}$
	Neutron	1.67×10^{-27}	0
* size exaggerated	Electron	9.11×10^{-31}	-1.602×10^{-19}

Electric current is the **rate of charge flow** (A = C/s)

Power is the rate of doing work or **the rate of using energy**. (W = J/S)

Power = Voltage x Current

Energy is the **amount of power** produced or consumed **over a given time**. J = W x s

Ohm's Law

Georg Ohm (16 March 1789 – 6 July 1854) was a German physicist and mathematician. As a school teacher, Ohm began his research with the new electrochemical cell, invented by Italian scientist Alessandro Volta. Ohm found that there is a direct proportionality between the potential difference (voltage) applied across a conductor and the resultant electric current. This relationship is known as Ohm's law:

Power from the Argon

The Particle device has three pins related to power:

- 3.3V: 500mA of power to be used for most hardware
- V_{USB}: 5V from the USB cable to power 5V hardware
- GND: The ground pin to close the electrical loop

Measuring Voltage, Current, and Resistance

One Resistor

Using your multimeter, measure the voltage "across" and current "through" the resistor.

Kirchhoff's First Law

Gustav Robert Kirchhoff (12 March 1824 – 17 October 1887) was a German physicist who contributed to the fundamental understanding of electrical circuits. His first law:

In an electrical circuit, the sum of currents flowing into that node is equal to the sum of currents flowing out of that node

i1 + i2 = i3 + i4

Kirchhoff's Second Law

The directed sum of the potential differences (voltages) around any closed loop is zero.

$$V4 - (V1 + V2 + V3) = 0$$

Kirchhoff's Second Law

Resistors in Series and Parallel

Resistors in Series and Parallel

$$R_{eq} = R_1 + R_2 + R_3$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

Resistors in Series

$$V_{cc} = V_1 + V_2 + V_3 \quad (1)$$

$$V_{cc} = IR_1 + IR_2 + IR_3 \quad (2)$$

$$V_{cc} = I(R_1 + R_2 + R_3) \quad (3)$$

Node Law: $I = I_1 = I_2 = I_3$

Loop Law:
$V_{cc} - (V_1 + V_2 + V_3) = 0$

$$\boxed{R_{eq} = R_1 + R_2 + R_3} \quad (4)$$

Resistors in Parallel

Node Law: $I = I_1 + I_2$

Loop Law: $V_{cc} = V_1 = V_2$

$$I = I_1 + I_2 \tag{5}$$

$$I = \frac{V_1}{R_1} + \frac{V_2}{R_2} \tag{6}$$

$$I = \frac{V_{cc}}{R_1} + \frac{V_{cc}}{R_2} \tag{7}$$

$$\frac{V_{cc}}{R_{eq}} = V_{cc}(\frac{1}{R_1} + \frac{1}{R_2}) \tag{8}$$

$$\boxed{\frac{1}{R_{eq}} = (\frac{1}{R_1} + \frac{1}{R_2})} \tag{9}$$

Assignment: L02_00_Resistors

- In your lab notebook, draw the circuit diagrams
  1. Series: $5.1k\Omega$ and $1.2k\Omega$
  2. Parallel: $5.1k\Omega$ and $1.2k\Omega$
  3. Combined: Two parallel $5.1k\Omega$ in series with $1.2k\Omega$
- Calculate the combined resistance, the voltage at each node, and the current through each component.
- Create Fritzing diagram.
- Build **(one at a time)** on your breadboard and test your calculations with a multimeter.

Diodes

The key function of a diode is to control the direction of current-flow. Current passing through a diode can only go in one direction, called the forward direction. Current trying to flow the reverse direction is blocked.

Light Emitting Diodes

LEDs (that's "ell-ee-dees") are a particular type of diode that convert electrical energy into light.

Current Limiting Resistors

As an LED has very little resistance, when it is connected directly to a power supply, the current draw will exceed its specifications and it will burn out.

$$V_{cc} - V_{LED} = IR \Longrightarrow R >= \frac{V_{cc} - V_{LED}}{I_{max}}$$

For a 3.3V power supply, a 0.43V across the LED, and a max current of 100mA, the resistor needs to be greater than 29Ω.

SYSTEM_MODE

System modes help control how the device manages the connection with the cloud. By default, the device connects to the Cloud and processes messages automatically. However there are many cases where a user will want to take control over that connection. There are three available system modes:

- AUTOMATIC,
- SEMI_AUTOMATIC,
- MANUAL.

```

//The below is placed in the header before Void Setup()

// SYSTEM_MODE(AUTOMATIC);      // Default if no SYSTEM_MODE included
   SYSTEM_MODE(SEMI_AUTOMATIC); // Uncomment if using without Wifi
// SYSTEM_MODE(MANUAL);         // Fully Manual
```

Assignment L02_01_helloLED

- Using Pin D1 as an output and the appropriate current limiting resistor, blink the LED once per second.
- Measure the voltage at both leads of the LED and record the voltage in your notebook.
- Change the resistor to $1k\Omega$ and then $10k\Omega$. What happens to the brightness? Measure the voltage and current in each case. Record in your notebook.

REMEMBER: Lab notebook, Fritzing, breadboard, then code

Constants and Variables

It is often useful to give a name to something that will be used repeatedly in the code. Such items can be constants or variables:

- A **Constant** is a declaration that does not change throughout the code. For example, the pin that an LED is attached to.
- A **Variable** is a declaration that changes as the code processes. For example, a counter or index.

The use of Constants and Variables has several advantages:

- It improves readability by assigning names to items.
- Items can be changed by editing a single declaration.
- It allows the code to do math.

The first two Data Types that we will be using:

- **int**: an Integer between $\pm 2,147,483,648$.
- **float**: a Floating point number with 7-digits precision.

IoT Style Guide - camelCase

Camel Case is the practice of writing phrases without spaces or punctuation, indicating the separation of words with a single capitalized letter, and the first word starting with either case. In IoT, we will start the first word as lowercase and subsequent words with upper case to delineate words.

Operators

There are a number of operators that act on variables:

```
// Assignment
x = y;       // assign x to be equal to y

// Math Operators
sum = x + y;
difference = x - y;
product = x * y;
quotient = x / y;
remainder = x % y;

// Incrementing
i = i + 1;
i += 1;
i++;

// Decrementing
i = i - 1;
i -= 1;
i--;

// Comparison
(x == y); // true if x is equal to y
(x != y);    // true if x is not equal to y
(x > y);     // true if x is greater than y
(x >= y);    // true if x is greater than or equal to y
(x < y);     // true if x is less than y
(x <= y);    // true if x is less than or equal to y
```

Constants and Variables Example

```
const int LEDPIN = 5;
const int LEDDELAY = 1000;
int i;

void setup() {
  pinMode(LEDPIN, OUTPUT);//set LEDPIN as Output
  i = 100;
}
void loop() {
  digitalWrite(LEDPIN,HIGH);
  delay(LEDDELAY);
  digitalWrite(LEDPIN,LOW);
  delay(LEDDELAY+i);
  i = i + 100;
}
```

Assignment L02_02_helloLEDvar

- Refactor your L02_01_helloLED code to use constants and/or variables.

Note: refactoring code is when you rewrite portions of your code to make it more readable, or to make it run more efficiently.

Pulse Width Modulation

Software Configurable:

- Digital Input: High/Low (3.3V/0V)
- Digital Output: High/Low (3.3V/0V)
- Analog Input: 0V to 3.3V
- Analog Output: 0V to 3.3V PWM

Assignment L02_03_helloLEDanalog

Use analogWrite to change the brightness of the LED, using values:

- 255
- 63
- 171
- 16

Measure the voltage with your multimeter at each value.

Syntax: analogWrite(pin,value);

- pin: the pin to write to
- value: the duty cycle of the pulses, an int between 0 (always off) and 255 (always on)

Flowcharts

Symbol	Name	Function
	Process	Indicates any type of internal operation inside the Processor or Memory
	input/output	Used for any Input / Output (I/O) operation. Indicates that the computer is to obtain data or output results
	Decision	Used to ask a question that can be answered in a binary format (Yes/No, True/False)
	Connector	Allows the flowchart to be drawn without intersecting lines or without a reverse flow.
	Predefined Process	Used to invoke a subroutine or an Interrupt program.
	Terminal	Indicates the starting or ending of the program, process, or interrupt program
	Flow Lines	Shows direction of flow.

Loops

FOR LOOP
initialize index
Condition?
Do something
increment index
WHILE LOOP
Condition?
Do something
DO WHILE LOOP
Do something
Condition?

FOR Loop syntax

```
// FOR loop syntax
for (initialization; condition; increment) {
  // statement(s);
}

// EXAMPLE
for (j=0; j <= 255; j++) {
  analogWrite(LEDPIN, j);
}
```

Note: the third parameter of a FOR loop can also decrement; i.e. $j--$ or can go up or down by a specified amount; i.e. $j = j + 2$

WHILE loop syntax

```
// WHILE loop syntax
while (condition) {
  // statement(s)
}


// EXAMPLE
while (button == HIGH) {
  digitalWrite(LEDPIN, HIGH);
} //continue this loop until button is released
```

For vs While Loops

For vs While Loop

Comparison Chart

For Loop	While Loop
The for loop is used for definite loops when the number of iterations is known.	The while loop is used when the number of iterations is not known.
For loops can have their counter variables declared in the declaration itself.	There is no built-in loop control variable with a while loop.
This is preferable when we know exactly how many times the loop will be repeated.	The while loop will continue to run infinite number of times until the condition is met.
The loop iterates infinite number of times if the condition is not specified.	If the condition is not specified, it shows a compilation error.

DifferenceBetween.net

Assignment L02_04_helloLEDtri

Using a FOR Loop, have the LEDs follow a Triangle Wave function from off to full brightness with a period of 10 seconds.

Before you write code, create a flow chart of the logic to create a triangle wave.

While or Do While

Number Systems

Decimal

92_{10}

Digits: 0,1,2,3,4,5,6,7,8,9

Binary

01011100_2

Digits: 0,1

Hexadecimal

$5C_{16}$

Digits: 0,1,2,3,4,5,6,7,8,9,A,B,C,D,E,F

Octal

134_8

Digits: 0,1,2,3,4,5,6,7

Exponents

The rule for zero as an exponent:

Any nonzero real number raised to the power of zero is one, this means anything that looks like x^0 will always equal 1 if x is not equal to zero.

Bits, Nibbles, Bytes, and Words

Data Types: Numbers

Data Type	8-bit AVR systems (Arduino Uno)			32-bit ARM systems (Teensy 3.2)		
	bytes	range (signed)	range (unsigned)	bytes	range (signed)	range (unsigned)
char	1	-128 to 127	0 to 255	1	-128 to 127	0 to 255
short	2	+/- 32,767	0 to 65,353	2	+/- 32,767	0 to 65,353
int	2	+/- 32,767	0 to 65,353	4	+/- 2,147,483,648	0 - 4,294,967,295
long	4	+/- 2,147,483,648	0 - 4,294,967,295	4	+/- 2,147,483,648	0 - 4,294,967,295
long long	8	+/- 9,223,372,036,854,770,000	0 to 18,446,744,073,709,551,615	8	+/- 9,223,372,036,854,770,000	0 to 18,446,744,073,709,551,615
float	4	3.4E +/- 38 (7 digits)	n/a	4	3.4E +/- 38 (7 digits)	n/a
double	4	3.4E +/- 38 (7 digits)	n/a	8	1.7E +/- 308 (15 digits)	n/a
long double	8	1.7E +/- 308 (15 digits)	n/a	8	1.7E +/- 308 (15 digits)	n/a
Unambiguous						
uint8_t	1	n/a	0 to 255	1	n/a	0 to 255
int8_t	1	-128 to 127	n/a	1	-128 to 127	n/a
uint16_t	2	n/a	0 to 65,353	2	n/a	0 to 65,353
int16_t	2	+/- 32,767	n/a	2	+/- 32,767	n/a
uint32_t	4	n/a	0 - 4,294,967,295	4	n/a	0 - 4,294,967,295
int32_t	4	+/- 2,147,483,648	n/a	4	+/- 2,147,483,648	n/a

There are $7.5x10^{18}$ grains of sand on Earth. A long long integer and the floating point numbers are larger than this.

MATH NOTE: An Integer divided by an Integer always returns an Integer

Math Warning and Type Casting

Be cognizant of the data type when performing math operations.

```
int x = 3;
int y = 2;
float yf = 2.0;
float z;

//int divided by an int returns an int
z = x/y;                        // z = 1.0
z = x/yf;                       // z = 1.5
z = x / 2;                      // z = 1.0
z = x / 2.0;                    // z = 1.5

//type casting used to change datatype
z = (float) x / (float) y;  // z = 1.5
z = x / (float) y;          // z = 1.5

z = (int) (x / yf);         // z = 1.0
y = x / yf;                 // y = 1
```

Type Casting is a way to ensure that you are correctly moving between datatypes

Pi (π)

$$\frac{\text{Circumference}}{\text{Diameter}} = \pi = 3.14159\ldots$$

Unit Circle and Trigonometric Functions

The Unit Circle is a circle with a radius of 1.

The Unit Circle can be used to map out the trigonometric values of sine, cosine, and tangent.

Unit Circle and the Value of $sin(\theta)$

- $sin(\theta)$ is the y-value of the point on the Unit Circle at angle θ.
- In our trig functions, θ is measured in radians (rad), not degrees.
- 360 degrees $= 2\pi$ radians.

Sine Waves

$$y = A * sin(2 * \pi * \nu * t) + B$$

where A = amplitude, B = offset, ν = frequency = $\frac{1}{period}$, and t = time in seconds.

Using Desmos (desmos.com/calculator)

Header Files

A header file is a file with the extension .h which contains C function declarations and macro definitions to be shared between several source files. There are two types of header files; those that the programmer writes and those that come with the compiler.

Both the user and system header files are included using the preprocessing directive #include. It has the following two forms:

- #include $<$ *file.h* $>$ for system header files.
- #include "*file.h*" for user-created header files in the directory that contains the current code.

An example of a system header file is the math.h header that defines various mathematical functions.

Basic Structure of IoT Program Revisited

```
#include <math.h>          // include header files
const int LEDPIN = 5;      // declare constants
float value,n;             // declare variables

void setup() {              // runs once
  pinMode(LEDPIN,OUTPUT); // system settings
  n = 0;                    // set variables
}

void loop() {               // loops indefinitely
  value = sin(2*M_PI*n);
  n = n+0.25;          // move a quarter around
                       // the unit circle
}
```

Assignment L02_05_helloLEDsin

Use a sin() function to vary the brightness of your LED.

- Use math.h.
- Function sin() takes a float as an input and returns a float.
- Set the period to 5 seconds.

Recall: for a sin wave: $y = A * sin(2 * \pi * \nu * t) + B$

The function millis() returns milliseconds since the Argon has been powered on. For the sine equation, use t = millis() / 1000.0.

Why is adding the decimal after 1000 important?

Module 3 - Buttons

IoT Fun

PARENTING in 1984
Did you REALLY brush your teeth or did you just WET THE BRISTLES to make it seem like you did?
www.ITworld.com
PARENTING in 2014
Did you REALLY brush your teeth or did you just HACK YOUR TOOTHBRUSH to make it seem like you did?
PJ

Displaying to the Screen: The Serial Monitor

```
void setup() {

// Enable Serial Monitor
  Serial.begin (9600);
  waitFor(Serial.isConnected,10000); // wait for
   Serial monitor
  Serial.println ("Ready to Go");
}

void loop() {
  for (i=0; i<=13; i++){
    Serial.print(i);
    delay(printDelay);
  }
}
```

Print Statements

1. Serial.print() prints data to the monitor through the serial port as human-readable text:
   - Serial.print('N') prints: N (works for single character only)
   - Serial.print("Hello World") prints: Hello World
   - Serial.print(78) prints: 78
   - Serial.print(3.141592) prints 3.14
   - Serial.print(3.141592,5) prints 3.14159
2. Serial.println() displays the print() followed by a carriage return (\r) or newline (\n).
3. Serial.printf() displays a formatted print.

Format Specifiers Statements

specifier	Output	Example
d *or* i	Signed decimal integer	392
u	Unsigned decimal integer	7235
o	Unsigned octal	610
x	Unsigned hexadecimal integer	7fa
X	Unsigned hexadecimal integer (uppercase)	7FA
f	Decimal floating point, lowercase	392.65
F	Decimal floating point, uppercase	392.65
e	Scientific notation (mantissa/exponent), lowercase	3.9265e+2
E	Scientific notation (mantissa/exponent), uppercase	3.9265E+2
g	Use the shortest representation: %e or %f	392.65
G	Use the shortest representation: %E or %F	392.65
a	Hexadecimal floating point, lowercase	-0xc.90fep-2
A	Hexadecimal floating point, uppercase	-0XC.90FEP-2
c	Character	a
s	String of characters	sample
p	Pointer address	b8000000
n	Nothing printed. The corresponding argument must be a pointer to a signed int. The number of characters written so far is stored in the pointed location.	
%	A % followed by another % character will write a single % to the stream.	%

```
int count = 42;
float value = 3.14159;
Serial.printf("Print an integer %i and a float %0.4f\n",count,value);

//Output: Print an integer 42 and a float 3.1416 (it rounded the last digit)
```

Opening the Serial Monitor

Access the Command Palette - Ctrl-Shift-P

Or, opent the Serial Monitor in Powershell or Terminal:

```
particle serial monitor --follow
```

Assignment L03_00_SerialMonitor

1. Print Hello World to your monitor screen.
2. Next, display to the screen a count from 0 to 13, separated by commas, three times by using:
   - Serial.print();
   - Serial.println();
   - Serial.printf();

One Pin - Many Functions

Software Programmable: Input or Output and Digital or Analog.

Digital Input/Output

Digital electronics rely on binary logic to store, process, and transmit data or information. Binary Logic refers to one of two states – ON or OFF. This is commonly translated as a binary 1 or binary 0. A binary 1 is also referred to as a HIGH signal and a binary 0 is referred to as a LOW signal.

- digitalWrite(pin,value);
- inputValue = digitalRead(pin);

where, value equals HIGH or LOW.

Switches

Lamp Off

Lamp On

Poles and Throws

- Poles indicates the number of circuits that one switch can control for one operation of the switch.
- Throws indicates the number of contact points.

A Button - SPST

SPST

double break

Floating Inputs

Pull Down and Pull Up Resistors

- What happens if the digital pin is left floating when the switch is open?
- What happens if the pin is connected directly to GND (or V_{cc}) without a resistor?

Our First Button and Pull Down Resistors

Reading from a digital pin:

- inputValue = digitalRead(pin);
  where
  - pin is the digital pin that the button is connected to
  - inputValue is an int (declared in the header)

Model Based Troubleshooting

Assignment: Buttons

- Notebook: draw circuit
- Fritzing diagram
- Wire your circuit
- Write the code

Connect a button (and a multimeter to measure the voltage) to Pin D3.

1. L03_01_button
   - Use digitalRead() to input the button state.
   - Print button state to the screen.
   - Remove the resistor. How does this affect the button state and the voltage?
   - Replace the pull-down resistor with a pull-up. How does the logic change?
     - Not pressed: 3.3V
     - Pressed: GND
2. L03_02_button_input_pulldown
   - Return to the "pull-down" configuration but without the pull-down resistor.
   - Implement: pinMode(pin,INPUT_PULLDOWN);

IF-ELSE Statements

IF-ELSE Statements

```
// IF statement SYNTAX
if (condition) {
  //statement(s)
}
else {
  // else statement(s)
}

// EXAMPLE
if (buttonState) {
  Serial.printf("Button is pressed \n");
}
else {
  Serial.printf("Button is not pressed \n");
}
```

Data Types: Boolean and Boolean Logic

Boolean datatype (bool) holds either a TRUE or FALSE

Boolean Logic Operations (condition statements)

1. NOT (!): true if operand is false and visa-versa
   - $x = !x$
2. AND (&&): true if both operands are true
   - $z = x \&\& y$
3. OR (||): true if either operand is true
   - $z = x \parallel y$

Boolean Logic In Action

```
bool x;
bool buttonState1, buttonState2;
int y, z;

// ! (NOT) assignment function
x = !x;        // toggle x (if x = 1, then set x = 0, and visa-versa)

// ! (NOT) comparison
if (!x) {      // if x is false
  // do something
}

// LOGICAL AND: if both pins are pressed
buttonState1 = digitalRead(PIN1);
buttonState2 = digitalRead(PIN2);
if ((buttonState1) && (buttonState2) {
  // do something
}

// LOGICAL OR: if either value is greater than zero
if (y > 0 || z > 0) {
  // do something
}
```

Button and LED

Assignment: Buttons and LEDs

Update your schematic and Fritzing

1. L03_03_buttonLED
   - Add a Green LED to Pin D6 and use D3 button to turn the LED on/off.
   - Also, print button state to the screen
2. L03_04_twoButtonLED
   - Add a second button (Pin D2) and Yellow LED (Pin D5).
   - Have each button control one LED.
   - Also, print button states to the screen.
3. Extra Credit: Modify twoButton
   - The Green LED lights up if both buttons are pressed
   - The Yellow LED lights up if either button is pressed

Resistors in Series and Parallel

Open Circuit Behavior

$$V_{out} = V_{in}\frac{IR_2}{I(R_1+R_2)} = \frac{R_2}{R_1+R_2}V_{in}$$

Behavior Under Load

$$V_{out} = \frac{R_2 \| R_L}{R_1+R_2\|R_L}V_{in}$$

Voltage Dividing

We are just using the Argon to provide Power and GND.

- Use various combinations of resistors between $1k\Omega$ and $22k\Omega$.
- Calculate the Series resistance and the voltage between the two resistors in your Lab Notebook.
- Measure with your multimeter and compare.

Potentiometer - Variable Resistor

A potentiometer has 3 pins. Two terminals (the blue and green) are connected to a resistive element and the third terminal (the black one) is connected to an adjustable wiper.

Assignment L03_05_AnalogInput

1. Look up the syntax of analogRead() in the Arduino Reference (https://www.arduino.cc/reference)
2. Utilize analogRead() to measure analog input across a potentiometer (voltage divider) using Pin A0.
3. Determine the range of the analogRead() across the entire range of the potentiometer.

Conjuction Junction

Anatomy of a Function

Anatomy of a C function

Datatype of data returned, any C datatype

"void" if nothing is returned

Function name

Parameters pass to function, any C datatype

```
int myMultiplyFunction(int x, int y){

    int result;

    result = x * y;
    return result;
}
```

Return statement, datatype matches declaration

Curly braces required

Functions in Action

```
int variable1, variable2, answer;

// Declare (or prototype) the function in the header
int myMultiplyFunction(int x, int y);

void setup() {
  Serial.begin(9600);
}

void loop() {
  // Call the function
  answer = myMultiplyFunction(variable1, variable2);
  Serial.printf("%i times %i = %i\n",variable1, variable2, answer);
  variable2 = answer;
}

// Define the function
int myMultiplyFunction(int x, int y) {
  int result;

  result = x * y;
  return result;
}
```

The function needs to be: Declared, Defined, and Called (at least once)

Types of Variables

```
int x;            // x is a global variable available in the entire program
int addx();       // declaration of function
void setup() {
  x = 1;
}
void loop() {
  x = addx();
}
int addx() {
   int y = 0;          // y is a local variable, resets every function call
   static int z = 0;   // z is a static local variable, maintains its value
   y = y + x;          // x is global, so value exists in function
   z = z + x;
   Serial.printf("x = %i, y = %i, and z = %i \n",x,y,z);
   return z;
}
```

1. Global Variables
   - Accessible throughout the program and all functions.
2. Local Variables
   - Accessible only in the function.
   - Created when function is called. Destroyed when function is returned.
3. Static Local Variables
   - Accessible only in the function.
   - Maintains value across multiple calls of a function.

Basic Structure of IoT Program with Functions

```
/*
 * This is an example of how to use functions
 * The code below converts inches to feet
 */

const int INCHPIN=14;
int inches;
float feet;

float inchestoFeet(int measurement);

void setup() {
  Serial.begin(9600);  // Turn on Serial Monitor
  while(!Serial);      // Wait for Serial Monitor to be running
  pinMode(INCHPIN,INPUT);
}

void loop() {
  inches = analogRead(INCHPIN);
  feet = inchestoFeet(inches);
  Serial.printf("%i inches equal %0.2f feet \n",inches, feet);
  delay(1000);
}

float inchestoFeet(int measurement) {
  float answer;            // declare answer as a local variable

  answer = measurement / 12.0;
  return answer;
}
```

Assignment L03_05_AnalogInput Revisited

1. Modify your code by adding a function, intoVolts(), that converts the analog input value to voltage.
2. Print both the raw analogInput and the associated voltage to your screen.

Photodiode

PARAMETERS	DIODE	PHOTODIODE
Definition	A diode is two terminal device which conducts when it is forwards biased.	A photodiode is a two terminal device which conducts when it is reversed biased.
Circuit symbol		
Main Function	Diode is mainly used as a switch.	Photodiode is used for conversion of light energy into electrical energy.
Material Used	Germanium or silicon, any of these two can be used.	Silicon is used for manufacturing photodiode. An anti-reflective layer of Silver Nitride is used for coating.
Applications	Used in clippers, clampers, rectifiers etc.	Used in optoelectronic device, camera, optocouplers etc.

Assignment: L03_06_HelloNightLight

- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

1. L03_06_HelloNightLight
   - The anode of the photodiode is connected to Pin A1. *Note, unlike an LED, the cathode (short pin) of the photodiode is connected to 3.3V.*
   - The LED anode to Pin D1.
   - Using analogRead/digitalWrite, turn on the LED when the photodiode is dark.
   - Using analogWrite, turn on the LED slowly as the room darkens.

Analog Resolution - ADC

Analog Resolution - DAC

analogWrite() resolution can be modified between 2 and 31 bits.

```
analogWriteResolution(pin,bits);
```

Analog Resolution - ADC

Particle Publish

One of the advantages of the Particle is seamless publishing to the Cloud.

EVENTS VITALS HEALTH CHECK

Search for events ADVANCED

NAME	DATA	DEVICE	PUBLISHED AT
particle/device/updat...	false	Lalonde	10/3/20 at 1:21:01 pm
spark/device/diagnost...	{"device":{"network":{"s...	Lalonde	10/3/20 at 1:21:00 pm
spark/device/app-hash	B665BE9CD4ABE921E3...	Lalonde	10/3/20 at 1:21:00 pm
Humidity	42.000000	Lalonde	10/3/20 at 1:20:58 pm
Pressure	29.780001	Lalonde	10/3/20 at 1:20:58 pm
Temperature	69.129997	Lalonde	10/3/20 at 1:20:58 pm
particle/device/updat...	false	Lalonde	10/3/20 at 1:20:58 pm
particle/device/updat...	true	Lalonde	10/3/20 at 1:20:58 pm
spark/device/last_reset	dfu_mode	Lalonde	10/3/20 at 1:20:58 pm
spark/status	online	Lalonde	10/3/20 at 1:20:58 pm

```
float temp, prs, hum;   // BME280 variables
String Temp, Prs, Hum;  // Strings to hold BME280 values

void loop() {
  Temp = String(temp);
  Prs = String(prs);
  Hum = String(hum);
  Particle.publish("Temperature", Temp, PRIVATE);
  Particle.publish("Pressure", Prs, PRIVATE);
  Particle.publish("Humidity", Hum, PRIVATE);
}
```

Modify L03_06_NightLight to publish the photodiode and LED values to the Particle Cloud once every 2 seconds.

Optional Week 1 Review: L03_00_SOS

- Flowchart is in english, not code syntax
- Wire one button and one LED to your Argon
- Declare the appropriate global variables and constants
- First function: void sos
- Second function: void flasher with parameters number of flashes, on time, off time between flashes
- Variables within the functions should be local, not global

Module 4 - NeoPixels

Smart Communities

Objects

Object-oriented programming
CLASS
Human
OBJECTS
Name
PROPERTIES
Email
Address
METHODS
Verify
Send mail
©2019 TECHTARGET. ALL RIGHTS RESERVED

Traffic Light

Let's use the traffic light to build our own Objects.

State Machine - Traffic Lights, British Style

SWITCH...CASE syntax - multiple IFs

```
// SWITCH...CASE syntax
switch (variable) {
  case constant1:
    // statements
    break;
  case constant2:
    // statements
    break;
  case constant3:
    // statements
    break;
  default:
    // statements
    break;
}
```

The variable is compared to the constants and the applicable code is called. If variable doesn't match any of the constants, then the default case is called.

Enumeration (enum)

The C-language has a user-defined datatype, enum, which allows the user to create a variable with various names for each of its states.

- Within the enum declaration descriptive tags are used.
- Then the compiler assigns the tags an integer value.

```
// Datatype State: the four traffic light states
enum State{
  GREEN,
  YELLOW,
  RED,
  RED_YELLOW
};  //note the ; after the }
```

The compiler treats enum as your personal variable type. For example, the enum variable (e.g., State) can now be used within switch...case statements.

Preprocessor commands

The C-compiler preprocesor executes the # commands before converting the program into code the microcontroller can understand.
We have previously used the #include preprocessor command. Now, we will learn a few more:

```
#ifndef _BUTTON_H_   //if not defined, then execute the rest of code

  #define _BUTTON_H_ //define the label

  // Place your Header.h code here

#endif // _BUTTON_H_
```

- #ifndef - if the label is not defined, then execute code until #endif
- #define - define the label
  - the #define label can be set to a value
  - the compiler then replaces the label with the value where ever it sees it meaning it is the similar to const <datatype> = <value>.
  - NOTE: we will use the CONSTANT and not the #define

Soldering

Soldering is one of the most fundamental skills needed to construct IoT devices.

- Solder the Noun: the alloy (a substance composed of two or more metals) that typically comes as a long, thin wire in spools or tubes
- Solder the Verb: to join together two pieces of metal in what is called a solder joint.

So, we solder with solder!

Soldering

- Lead vs Lead-free: Traditionally, solder was composed of mostly lead (Pb), tin (Sn), and a few other trace metals. However, lead is hazardous in large quantities.
    - Lead solder has superior properties - lower melting point, flows well, less internal flaws after cooling.
    - Lead-free solder has a higher melting point and thus needs assistance to flow. Many have flux core, a chemical that aids in the flowing.
- Solder flux: Flux is a chemical cleaning agent used before and during the soldering process of electronic components. The flux also protects the metal surfaces from re-oxidation during soldering and helps the soldering process by altering the surface tension of the molten solder.

Solder Irons

- Solder tips - the tip transfers heat, raising the temperature of the metal components to the melting point of the solder. They come in a variety of shapes and sizes.
- Wand - the wand holds the tip and may have a separate base. The wand controls the temperature of the tip. The temperature range depends on the type of solder.
  - Lead solder - 600°-650°F (316°-343°C)
  - Lead-free solder - 650°-700°F (343°-371°C)
- Brass Sponge - During soldering the tip will start to oxidize, it will change color and less readily accept solder. The brass sponge will reduce buildup. Alternatively, a wet sponge can be used.

Solder Tip Care

CLEANING YOUR TIPS

To clean your tips, use either **brass or stainless steel wool.** Brass wool is softer and less abrasive, while the harder stainless steel wool has a longer life. After cleaning, immediately wet the tip with fresh solder to **prevent oxidation.**

TINNING YOUR TIPS

Tinning stops your tips from oxidizing by creating a **protective layer** between the air and the iron. Preventing oxidation through tinning **extends the life** of your tips.

OXIDIZED TIP TINNED TIP

Properly Storing Tips

If storing your tips for an extended period, you should **clean and tin them before putting them away,** which will help prevent them from oxidation. After letting them cool, you may also want to **store them in a sealed container** to further **protect them** from oxidation, humidity and contamination.

Good vs Bad Solder Joints

Don't: Use the very tip of the iron.
Do: Use the side of the tip of the iron, "The Sweet Spot."

Do: Touch the iron to the component leg and metal ring at the same time.

Do: While continuing to hold the iron in contact with the leg and metal ring, feed solder into the joint.

Don't: Glob the solder straight onto the iron and try to apply the solder with the iron.

Do: Use a sponge to clean your iron whenever black oxidization builds up on the tip.

A Solder flows around the leg and fills the hole - forming a volcano-shaped mound of solder.

B Error: Solder balls up on the leg, not connecting the leg to the metal ring.
Solution: Add flux, then touch up with iron.

C Error: Bad Connection (i.e. it doesn't look like a volcano)
Solution: Flux then add solder.

D Error: Bad Connection...and ugly...oh so ugly.
Solution: Flux then add solder.

E Error: Too much solder connecting adjacent legs (aka a solder jumper).
Solution: Wick off excess solder.

Desoldering

Solder Wick

Desoldering Pump

Generating Random Numbers

```
/*
 * The random() function generates pseudo-random
   numbers.
 *     random(min,max)
 *     random(max)     //assumes min = 0
 * returns a number between min and max-1
 */

  // print a random number from 0 to 299
  randNumber = random(300);
  Serial.printf("The number is = %i \n",randNumber);

  // print a random number from 10 to 19
  randNumber = random(10, 20);
  Serial.printf("The number is = %i \n",randNumber);
```

Nested Statements

- Loops and conditions can be nested within each other
- A nested loop is a loop within a loop, an inner loop within the body of an outer one. How this works is that the first pass of the outer loop triggers the inner loop, which executes to completion. Then the second pass of the outer loop triggers the inner loop again. This repeats until the outer loop finishes.
- The break command can be used to exit a loop before completion

Nested For Loops

```
int tens;
int ones;

// Nested FOR Loops
for(tens=0;tens<10;tens++) {
  for(ones=0;ones<10;ones++) {
    Serial.printf("Combining %i(tens) and %i(ones) gives %i%i\n",tens,ones,tens,ones);
  }
}

// An IF nested in Nested FOR Loops
for(tens=0;tens<10;tens++) {
  for(ones=0;ones<10;ones++) {
    if(tens != ones) {
      Serial.printf("Combining %i(tens) and %i(ones) gives %i%i\n",tens,ones,tens,ones);
    }
  }
}

// Using break to break out of a loop
for(tens=0;tens<10;tens++) {
  for(ones=0;ones<10;ones++) {
    Serial.printf("Combining %i(tens) and %i(ones) gives %i%i\n",tens,ones,tens,ones);
    if((tens+ones) = 10) {
      break;
    }
  }
}
```

NeoPixels

NeoPixels are:

- Addressable RGB LEDs based on the WS2812 (or WS2811) LED/drivers.
- They come as individual pixels, in strips, in matrices, rings, etc.
- They can be programmed via your microcontroller to create a wide array of effects and animations.

CYMK vs RGB Colors

CMYK / Print
(Subtractive Colors)

RGB / Screen
(Additive Colors)

NeoPixel Programming

Installing Libraries

Using the Command Palette within VSCode:

- ctrl-shift-p → Particle: Find Libraries
- ctrl-shift-p → Particle: Install Library

Move to Big Breadboard

Connect the 3.3V and ground rails together

Leave the 5V rail for the NeoPixels

Leave Space for Future Components

Direct Memory Access (DMA)

Many microcontrollers interface with Neopixels through any GPIO using the bit banging[5] approach.

The Photon2 has some bit banging limitations, so the Neopixels need to be controlled through DMA using either pin D2 (SPI1) or D15 (SPI[6]).

[5] bit banging is a "term of art" for any method of data transmission that employs software as a substitute for dedicated hardware to generate transmitted signals or process received signals.

[6] SPI Bus will be covered in detail later in the course

Using NeoPixel Class and Methods

```
#include <neopixel.h>

const int PIXELCOUNT = 16;  // Total number of NeoPixels

Adafruit_NeoPixel pixel(PIXELCOUNT, SPI1, WS2812B); //declare object
/* Argument 1 = Number of pixels
 * Argument 2 = GPIO pin number
 * Argument 3 = Pixel type flags, add together:
 * Use:
 *    WS2811          // 400 KHz datastream (NeoPixel)
 *    WS2812          // 800 KHz datastream (NeoPixel)
 *    WS2812B         // 800 KHz datastream (NeoPixel)
 *    WS2813          // 800 KHz datastream (NeoPixel)
 *    WS2812B2        // 800 KHz datastream (NeoPixel)
 *    SK6812RGBW      // 800 KHz datastream (NeoPixel RGBW)
 */
void setup() {
  pixel.begin();
  pixel.setBrightness(bri);                  // bri is a value 0 - 255
  pixel.show(); //initialize all off
}

void loop() {                                // n is the pixel number being set
  pixel.setPixelColor(n, red, green, blue); // red,green,blue = 0 - 255
  pixel.setPixelColor(n, color);             // hex code 0x000000 - 0xFFFFFF
  pixel.show();                              // nothing changes until show()
  pixel.clear();
  pixel.show();                              // even clear() needs a show()
}
```

Assignment: NeoPixels

- Notebook: flowchart
- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

1. L04_01_neoPixel
   - Using FOR loop and individual R/G/B, light up 16 pixels; small delay between.
2. L04_02_colorHeader
   - Implement a header file that contains the pixel colors.
3. L04_03_neoStrip, use setPixelColor() to:
   - Send a pixel of a random color down and back on the strip.
   - Send a pair of Maize and Blue lights down the strip.
   - Send pixels in different directions at the same time.
   - Have the pixels move at different speeds.

Arrays

- Syntax: datatype var[ ] = {element 1, element 2, element 3};
- Example: int c[ ] = {-45, 6, 0, 72, 1543, -89}

Using Arrays

```
int myInts[6];
int myPins[] = {2, 4, 8, 3, 6};
int mySensVals[6] = {2, 4, -8, 3, 2};
char message[6] = "hello";

void loop() {
  mySensVals[0] = 10; //assign value to array
  x = mySensVals[4];  //retrieve value from array
  for (i = 0; i < 5; i = i + 1) {
    Serial.printf("Pin %i selected \n",myPins[i])
   ;
  }
}
```

Note: An array index starts at 0 (not 1).

Assignment: NeoPixels (continued)

- Notebook: flowchart
- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

1. Add to L04_03_neoStrip, use setPixelColor() to implement functions:
   - Light the strip up as a rainbow.
2. L04_04_pixelFill, create a function:
   - Create a function called pixelFill with three parameters (start pixel, an end pixel, and hex color) that lights up a segment of the pixel strip.
   - Use pixelFill() to light 7 segments of your strip in the colors of the rainbow.
3. L04_05_pixelCTRL (extra credit)
   - Connect a button and potentiometer to your Argon
   - Use the button to change the color of your pixels
   - Use an analogRead() to determine how many pixels are lit up (0 to 45)

RandomSeed()

- The "pseudo" in pseudo-random indicates it is not truly random.
- randomSeed() initializes the pseudo-random number generator causing it to start at an arbitrary point in its random sequence. This sequence, while very long, and while appearing random, is always the same.
- If it is important for a sequence of values generated by random() to differ, on subsequent executions, use randomSeed() to initialize the random number generator with a fairly random input, such as an analogRead() on an unconnected pin.

```
// Leave an Analog Input (A0) floating
pinMode(A0,INPUT);
randomSeed(analogRead(A0));

// print a random number hex color value
randNumber = random(0x0000,0xFFFFFF);
Serial.printf("My color is 0x%06X \n",randNumber);
```

Algorithms

Algorithm
['al-gə-,ri-thəm]
A set of instructions for solving a problem or accomplishing a task.

Big O Notation

Big O notation is a way to describe the speed or complexity of a given algorithm.

- Big O notation tells the number of operations an algorithm will make.
- It gets its name from the literal "Big O" in front of the estimated number of operations.
- Big O establishes a worst-case run time

Bubble Sort

Bubble Sorting
First Pass
Second Pass
Third Pass
swapping
no swap
© w3resource.com

Bubble Sort Algorithm - O(n^2)

- Larger elements are swapped (one-by-one) with smaller ones (i.e., they float to the top)
- Takes O(n^2) iterations as there is a $(N-1)$ loop nested in a N loop.

Selection Sort

Insertion Sort

Quick Sort

QUICK SORT ALGORITHM

```
QuickSort(arr[], s, e)
{
  if(s<e)
  {
    p = Partition(arr[],s,e)
    QuickSort(arr[], s, (p-1))
    QuickSort(arr[], (p+1), e)
  }
}
```

Quick Sort Algorithm - O($nlog(n)$)

- Any pivot point is selected (in this case, the last element)
- Smaller elements are put to the left of the pivot, larger to the right.
- Each side of the pivot is then sorted using the same method. This is called recursion.
- This continues until everything is sorted.
- In general, this takes O($n\log(n)$) iterations

Assignment: L04_05_sorting

- Notebook: flowchart
- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

- Randomly fill an array of length equal to number of neopixels with colors from blue to red.
- Implement a function for the bubble sort that displays the change in the array after each iteration.
- Implement either the selection or insertion sort on a new random array
- (Optional) implement the quicksort

Module 5 - Encoders

IoT Humor

"WE HAVE TO GO OUT FOR DINNER. THE REFRIGERATOR ISN'T SPEAKING TO THE STOVE."

Avoiding Delays

```
void loop() {
  //run constantly
  currentTime = millis();

  //run once per second
  if((currentTime-lastSecond)>1000) {
    lastSecond = millis();
    Serial.printf(".");
  }

  //run once per minute
  if((currentTime-lastMinute)>60000) {
    lastMinute = millis();
    Serial.printf("\nMinute\n");
  }
```

Capacitors

A capacitor is created out of two metal plates and an insulating material called a dielectric. The metal plates are placed very close to each other, in parallel, but the dielectric sits between them to make sure they don't touch.

- The dielectric can be made out of all sorts of insulating materials; paper, glass, rubber, ceramic, plastic, or anything that will impede the flow of current.
- The plates are made of a conductive material; aluminum, tantalum, silver, or other metals.

Capacitors

When current flows into a capacitor, the charges get "stuck" on the plates because they cannot get past the insulating dielectric. Electrons build up on one of the plates, and it becomes overall negatively charged. The large amount of negative charges pushes away like charges on the other plate, making it positively charged.

The stationary charges on these plates create an electric field, which influences electric potential energy and voltage. When charges group together on a capacitor like this, the capacitor is storing electric energy just as a battery might store chemical energy.

Capacitors in Circuits

Capacitors in Circuits

RC Time Constant

$$V_c(t) = V_c(0) * e^{\frac{t}{-\tau}}$$

Capacitance is defined as:

$$C = \frac{Q}{V}\left(\frac{Coulombs}{Volt}\right)$$

The current through a capacitor is:

$$I = C\frac{\Delta V}{\Delta t}$$

And, therefore, the capacitor charges with a time constant (τ):

$$\tau = RC$$

Alternating Current

Low Pass Filter - cutoff frequency f_c

- At low frequencies, there is plenty of time for the capacitor to charge up to practically the same voltage as the input voltage.
- At high frequencies, the capacitor only has time to charge up a small amount before the input switches direction. The output goes up and down only a small fraction of the amount the input goes up and down. At double the frequency, there's only time for it to charge up half the amount.

$$f_c = \frac{1}{2\pi\tau} = \frac{1}{2\pi RC}$$

Low Pass Filter Response

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(500)(4.7x10^{-6})} = 67.5678Hz$$

Capacitors - does it matter how they are placed

- Some types of capacitors (electrolytic and tantalum) are polarized (they have + and - terminals). This is due to how the dielectric film has been deposited. The reverse polarity leads to degradation of the dielectric.
- Other capacitors (ceramic and film) do not have a polarity and can be installed in either direction.

True DAC on Argon

$analogWrite(pin, value, frequency)$

The Particle microcontrollers do not have a true DAC (Digital to Analog Converter). However, we can convert a PWM pin to a DAC signal using a low pass filter.

- The PWM signal oscillates at 500 Hz, but we can increase up to 50,000 Hz using a third parameter in analogWrite().
- Using $R = 470\Omega$ and $C = 0.47\mu F$ will give a $f_c = 720Hz$.

Assignment: Low Pass Filters

- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

1. L05_00_lowPass
   - Output 0.825V to pin A5 (no wire will be connected to this output).
   - Connect a potentiometer to A0. Use it to vary a frequency (ν) from 0 to 500 Hz.
   - Create a sine wave of frequency ν: $sin(2\pi\nu t)$ and output on the A1 pin. Set the PWM frequency to 50,000 Hz.
   - Create a DAC to convert the PWM signal on A1 to analog using a low pass filter with $f_c \approx 700Hz$
   - Create a low pass filter with $f_c \approx 67Hz$
   - Use an oscilloscope to measure the A5, A1, post DAC, and post low-pass filter.
   - Record in your notebook how the signals change when ν is varied with the potentiometer.

Encoders

Encoders

Clockwise Sequence

	A	B
t1	0	1
t2	0	0
t3	1	0
t4	1	1

Counter-Clockwise Sequence

	A	B
t1	1	0
t2	0	0
t3	0	1
t4	1	1

The Encoder Class

```
#include <Encoder.h>
Encoder myEnc(PINA,PINB);
// The "c" pin on the encoder is connected to GND

void setup() {
}

void loop() {
  // read encoder position
  position = myEnc.read();

  // set encoder to a position
  myEnc.write(maxPos);
}
```

Mapping (or Converting)

Mapping is the conversion from one set of units to another. For example converting from Celsius to Fahrenheit:

$$Temp(^\circ F) = \frac{9}{5} * Temp(^\circ C) + 32$$

C++ provides us with a function to do this mapping:
newVal = map(value, fromLow, fromHigh, toLow, toHigh);

For example:
tempF = map(tempC,0,100,32,212);

Assignment: Encoders

- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

1. L05_01_encoder
   - Display the encoder position to the screen, but only when encoder is moved.
   - What do you notice about the encoder position as you turn it slowly?
2. L05_02_NeoPixel
   - The encoder has 96 positions. Map the encoder input to 16 NeoPixels.
   - Bound the input, so the mapped range is from 0 to 15.
   - What is the difference in performance if you bind the input vs the mapped range?
   - Use the encoder to light up the four NeoPixels and the ring.

Encoder Jitter

Encoder - Low Pass Filter

Encoder - LEDs and Button

The encoder has a Red,Green, and Blue LED, as well as a Switch (technically a Button), that act like discrete components and are not associated with the Encoder.h library. Note, the LEDs are active low (the pins needs to be set to ground to activate the light).

Assignment: Encoders

- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

1. L05_03_encoder_switch
   - Connect the encoder switch and LEDs.
   - Use the switch to turn on/off the NeoPixels.
   - Set encoder LED to red for off and green for on.
   - Disable turning the encoder when off.
2. L05_04_rainbow1
   - Use a button to cycle the NeoPixel ring colors through the colors of the rainbow; one color change each time button is pressed.
3. L05_05_rainbow2
   - Have it continuously cycle (i.e, while pressed colors change every one second).

Module 6 - Servo

Servo Motors

- A servo is any motor-driven system with a feedback element built in.
- A servo motor basically has three core components:
  1. a DC motor,
  2. a potentiometer that measures its position,
  3. a feedback controller circuit
- The servo is controlled by a PWM signal from a digital pin. The width of the pulse determines the position that the servo moves to.

Servo library

The Particle Argon has the Servo class built-in, so no libary is needed.

1. Header
   - Servo myServo; - create object myServo of class Servo
2. void setup()
   - myServo.attach(pin) - attach the Servo object to a pin (this must be a PWM pin)
3. void loop()
   - myServo.write(angle) - move servo to angle (in degrees)

Assignment: L06_Servo

- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

1. L06_01_Servo
   - Connect the servo and a button to the Argon
   - Create a HelloServo-type code that moves the servo to 180 degrees, waits, and then moves it to zero.
   - Modify the code to have the servo oscillate between 0 and 180 degrees using a sine wave pattern.
   - Have the button to start and stop the motion.
   - Extra: Have the motion begin again at the point in the cycle where it stops.

Recall, in C++ (math.h) the math constants are M_<name>. For example, M_PI $= \pi$.

KeyPad

- The Keypad is a two-dimensional array of buttons.
- Pushing a button connects one row pin with one column pin.
- We will use the Keypad_Particle.h library to access the Keypad.
- NOTE: due to the onboard LED, you can not use Pin D7 for the keypad

2-dimensional arrays

- Declare Array: int c[3][6] = {{16,-2,2,-42,16,-2},{32,107,88,42,32,107},{-45,6,0,72,1543,-89}};
- Set a Cell: c[1][3] = 42;
- Access a Cell: x = c[1][3]; → x = 42

Char and Byte Datatype

- The char data type is a single byte in size and can be used to represent text characters (ASCII).
- Alternatively, the datatype byte can also be used for a single byte (8-bit number)

ASCII TABLE

Decimal	Hex	Char	Decimal	Hex	Char	Decimal	Hex	Char	Decimal	Hex	Char
0	0	[NULL]	32	20	[SPACE]	64	40	@	96	60	`
1	1	[START OF HEADING]	33	21	!	65	41	A	97	61	a
2	2	[START OF TEXT]	34	22	"	66	42	B	98	62	b
3	3	[END OF TEXT]	35	23	#	67	43	C	99	63	c
4	4	[END OF TRANSMISSION]	36	24	$	68	44	D	100	64	d
5	5	[ENQUIRY]	37	25	%	69	45	E	101	65	e
6	6	[ACKNOWLEDGE]	38	26	&	70	46	F	102	66	f
7	7	[BELL]	39	27	'	71	47	G	103	67	g
8	8	[BACKSPACE]	40	28	(	72	48	H	104	68	h
9	9	[HORIZONTAL TAB]	41	29	)	73	49	I	105	69	i
10	A	[LINE FEED]	42	2A	*	74	4A	J	106	6A	j
11	B	[VERTICAL TAB]	43	2B	+	75	4B	K	107	6B	k
12	C	[FORM FEED]	44	2C	,	76	4C	L	108	6C	l
13	D	[CARRIAGE RETURN]	45	2D	-	77	4D	M	109	6D	m
14	E	[SHIFT OUT]	46	2E	.	78	4E	N	110	6E	n
15	F	[SHIFT IN]	47	2F	/	79	4F	O	111	6F	o
16	10	[DATA LINK ESCAPE]	48	30	0	80	50	P	112	70	p
17	11	[DEVICE CONTROL 1]	49	31	1	81	51	Q	113	71	q
18	12	[DEVICE CONTROL 2]	50	32	2	82	52	R	114	72	r
19	13	[DEVICE CONTROL 3]	51	33	3	83	53	S	115	73	s
20	14	[DEVICE CONTROL 4]	52	34	4	84	54	T	116	74	t
21	15	[NEGATIVE ACKNOWLEDGE]	53	35	5	85	55	U	117	75	u
22	16	[SYNCHRONOUS IDLE]	54	36	6	86	56	V	118	76	v
23	17	[ENG OF TRANS. BLOCK]	55	37	7	87	57	W	119	77	w
24	18	[CANCEL]	56	38	8	88	58	X	120	78	x
25	19	[END OF MEDIUM]	57	39	9	89	59	Y	121	79	y
26	1A	[SUBSTITUTE]	58	3A	:	90	5A	Z	122	7A	z
27	1B	[ESCAPE]	59	3B	;	91	5B	[	123	7B	{
28	1C	[FILE SEPARATOR]	60	3C	<	92	5C	\	124	7C	|
29	1D	[GROUP SEPARATOR]	61	3D	=	93	5D	]	125	7D	}
30	1E	[RECORD SEPARATOR]	62	3E	>	94	5E	^	126	7E	~
31	1F	[UNIT SEPARATOR]	63	3F	?	95	5F	_	127	7F	[DEL]

ASCII: American Standard Code For Information Interchange

Keypad.h

```
#include <Keypad_Particle.h>

const byte ROWS = 4;
const byte COLS = 4;
char customKey;

char hexaKeys[ROWS][COLS] = {
  {'1', '2', '3', 'A'},
  {'4', '5', '6', 'B'},
  {'7', '8', '9', 'C'},
  {'*', '0', '#', 'D'}
};

byte rowPins[ROWS] = {D8,D9,D16,D15};   // 1st to 4th Keypad pins (starting on left)
byte colPins[COLS] = {D17,D18,D19,D14}; // 5th to 8th Keypad pins

Keypad customKeypad = Keypad(makeKeymap(hexaKeys), rowPins, colPins, ROWS, COLS);

void setup(){
  Serial.begin(9600);
}

void loop(){
  customKey = customKeypad.getKey();

  if (customKey){
    Serial.printf("Key Pressed: %c\n",customKey);
    Serial.printf("Key Pressed (Hex Code) 0x%02X\n",customKey); //ASCII Hex value
  }
}
```

Assignment: L06_02_Lock

- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

1. Design and print a lockholder based on the class example.
   - Optional: design and print your own gear and lock slider
2. Using the keypad, create a digital lock
   - Implement 4-digit digital "key" in an array.
   - Use the keypad to enter a code and store the entered code in an array
   - Create a bool function[a] that compares entered code array to the key array
   - Use the servo to lock and unlock based on a correctly entered code.
   - Light green LED and disengage lock when unlocked.
   - Light red LED and engage lock when locked.

[a] Remember to use local variables in the function

Assignment: L06_03_LockPick (Extra Credit)

1. Create a new project.
2. Create an electronic lock pick
   - Set servo to locked position.
   - Implement 4-digit digital "key" in an array as before.
   - Automatically generate a random guess at the "key"
   - Using your bool function compares random code array to the key array
   - Repeat until correct, and then open lock.
   - Print the number of guesses and the microseconds (micros()) taken from first guess to correct guess.
   - Using the reset button, run the entire code 10 times and document the variation in time to find the correct code.

Optional Designs

GEAR

LOCK SLIDER

Module 7 - I^2C

Buses and Interfaces

UART

Universal Asynchronous Receiver/Transmitter

- Each device have a transmit (Tx) and receive (Rx) pin.
- UART1 Tx is connected to UART2 Rx (and visa versa)

The USB Cable is a UART connection

① PVC Jacket
② 2.54mm pitch socket
③ 2.54mm 1*4p terminal ,female
④ USB A male, PL2303TA TTL 3.3V PCBA inside
⑤ Heat shrink tube, black, OD=5.0

1*4P Female Socket	Name	Colour	Description
Pin 1	TXD	White	Transmit Asynchronous Data
Pin 2	RXD	Green	Receive Asynchronous Data
Pin 3	GND	Black	Device ground supply
Pin 4	VCC	Red	+5V

Inter-integrated Circuit (I^2C)

I^2C Pullup Resistors

The I^2C drivers are "open drain". They can pull the corresponding signal line low, but cannot drive it high. This is done to prevent a short when one device is driving the bus low, while another is driving it high.

Each I^2C line needs a pull-up resistor on it to restore the signal to high when no device is asserting it low. The Teensy (and Argon) have internal pull-up resistors that are usually sufficient to restore the high signal. For I^2C greater than $1m$, an external $4.7k\Omega$ should be added to each line.

L07_00_I2CScanner

Let's create an I2C scanner

1. On your large breadboard, add the BME280 and OLED.
2. Follow along to create the I2C code.
   - Use library wire.h
   - Wire.begin();
   - Wire.beginTransmission(i);
   - Wire.endTransmission();
     - 0: Transmission Successful
     - 1: Data too long to fit in transmit buffer
     - 2: Received NACK (Negative Acknowledgment) on transmit of address
     - 3: Received NACK on transmit of data
     - 4: Other error
3. Determine the I2C addresses of each device, document in your lab notebook.

Char Datatype - Revisited

Reminder - the char data type is a single byte in size and can be used to represent text characters (ASCII).

ASCII control characters

00	NULL	(Null character)
01	SOH	(Start of Header)
02	STX	(Start of Text)
03	ETX	(End of Text)
04	EOT	(End of Trans.)
05	ENQ	(Enquiry)
06	ACK	(Acknowledgement)
07	BEL	(Bell)
08	BS	(Backspace)
09	HT	(Horizontal Tab)
10	LF	(Line feed)
11	VT	(Vertical Tab)
12	FF	(Form feed)
13	CR	(Carriage return)
14	SO	(Shift Out)
15	SI	(Shift In)
16	DLE	(Data link escape)
17	DC1	(Device control 1)
18	DC2	(Device control 2)
19	DC3	(Device control 3)
20	DC4	(Device control 4)
21	NAK	(Negative acknowl.)
22	SYN	(Synchronous idle)
23	ETB	(End of trans. block)
24	CAN	(Cancel)
25	EM	(End of medium)
26	SUB	(Substitute)
27	ESC	(Escape)
28	FS	(File separator)
29	GS	(Group separator)
30	RS	(Record separator)
31	US	(Unit separator)
127	DEL	(Delete)

ASCII printable characters

32	space	64	@	96	`
33	!	65	A	97	a
34	"	66	B	98	b
35	#	67	C	99	c
36	$	68	D	100	d
37	%	69	E	101	e
38	&	70	F	102	f
39	'	71	G	103	g
40	(	72	H	104	h
41	)	73	I	105	i
42	*	74	J	106	j
43	+	75	K	107	k
44	,	76	L	108	l
45	-	77	M	109	m
46	.	78	N	110	n
47	/	79	O	111	o
48	0	80	P	112	p
49	1	81	Q	113	q
50	2	82	R	114	r
51	3	83	S	115	s
52	4	84	T	116	t
53	5	85	U	117	u
54	6	86	V	118	v
55	7	87	W	119	w
56	8	88	X	120	x
57	9	89	Y	121	y
58	:	90	Z	122	z
59	;	91	[	123	{
60	<	92	\	124	|
61	=	93	]	125	}
62	>	94	^	126	~
63	?	95	_		

Extended ASCII characters

128	Ç	160	á	192	└	224	Ó
129	ü	161	í	193	┴	225	ß
130	é	162	ó	194	┬	226	Ô
131	â	163	ú	195	├	227	Ò
132	ä	164	ñ	196	─	228	õ
133	à	165	Ñ	197	┼	229	Õ
134	å	166	ª	198	ã	230	µ
135	ç	167	º	199	Ã	231	þ
136	ê	168	¿	200	╚	232	Þ
137	ë	169	®	201	╔	233	Ú
138	è	170	¬	202	╩	234	Û
139	ï	171	½	203	╦	235	Ù
140	î	172	¼	204	╠	236	ý
141	ì	173	¡	205	═	237	Ý
142	Ä	174	«	206	╬	238	¯
143	Å	175	»	207	¤	239	´
144	É	176	░	208	ð	240	≡
145	æ	177	▒	209	Ð	241	±
146	Æ	178	▓	210	Ê	242	‗
147	ô	179	│	211	Ë	243	¾
148	ö	180	┤	212	È	244	¶
149	ò	181	Á	213	ı	245	§
150	û	182	Â	214	Í	246	÷
151	ù	183	À	215	Î	247	¸
152	ÿ	184	©	216	Ï	248	°
153	Ö	185	╣	217	┘	249	¨
154	Ü	186	║	218	┌	250	·
155	ø	187	╗	219	█	251	¹
156	£	188	╝	220	▄	252	³
157	Ø	189	¢	221	¦	253	²
158	×	190	¥	222	Ì	254	■
159	ƒ	191	┐	223	▀	255	nbsp

ASCII 248

alt + 248
(Degree symbol)

most consulted

ñ	énye, n with tilde	(alt + 164)
■	black square	(alt + 254)
2	superscript two, square	(alt + 253)
°	degree symbol	(alt + 248)
'	apostrophe, single quote	(alt + 39)
µ	letter Mu, micro, micron	(alt + 230)
©	copyright symbol	(alt + 184)
®	registered trademark	(alt + 169)
3	superscript three, cube	(alt + 252)
á	a with acute accent	(alt + 160)

```
const char degree = 0xF8;  // Decimal 248 = 0xF8
float temp = 98.6;
void setup() {
  Serial.begin(9600);
  //NOTE: extended ASCII characters don't always print correct to Serial Monitor
  Serial.printf("My temperature is %0.1f %c",temp,degree);
}
```

A word about example code

Example code is sometime misleading as each author has their own style

1. .print() and .println() vs. .printf()
   - Some arduino-type embedded controllers don't have .printf() available as a command, so .print() and .println() are used instead.
   - Per the IoT Style Guide, we use .printf()
2. Serial.printf(F("Hello World"))
   - AMR Cortex is segmented into program memory and data memory.
   - The compiler usually stores Strings as constants in data memory.
   - The F() forces the String to be stored in program memory. This is useful when the data memory is "small"
   - The ARM Cortex compilers automatically store Strings in program memory, so F() is redundant and not needed.
3. #define pre-compiler directive
   - #define can be used to create a label that represents a value. Before compiling, the anywhere the label exists in the code, it is replaced by the value.
   - Our IoT Style guide is to use "const datatype NAME=value" instead of "#define NAME value"

Assignment: I^2C

- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

1. L08_00_Exmaple
   - Install Adafruit_SSD1306 library
   - Copy the SSD_1306_128x64_i2c example code to your .ino file
   - Run example changing the I2C address to match your OLED.
   - You will likely get an error and have to remove a random function in the example code. Why?
   - In your notebook document the commands to create an object, initialize the object, and the various commands to display text.

Assignment: I^2C (Continued)

- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

1. L07_01_OLEDWrite
   - Without cut/paste, using your notes and printf() display:
     - Hello World
     - Your Name using spanish honorific (señor, señora, señorita).
     - Your Birthday (e.g., 04/03/1968) using separate variables for month, day, and year.
   - Rotate screen using setRotation(rot) method.
     - rot is an int from 0 to 3
   - OPTIONAL: Make your own bitmap: `https://diyusthad.com/image2cpp` and `https://www.reduceimages.com`

L07_03_JumpingJackFlash (Extra Credit)

1. Using the SSD1306 Draw functions:
   - Create at least 5 different stick figure jumping jack frames
   - Use the frames to create an animation.
2. Add in Encoder functionality
   - Use the encoder switch to change between auto and manual
   - In auto, have the encoder change the speed of the animation
   - In manual, manually step through each frame with the encoder.

Using the Adafruit_BME280 class

```
// Define BME280 object
Adafruit_BME280 bme; //this is for I2C device

// Initialize the BME280 in void setup()
status = bme.begin(hexAddress);
if (status == false) {
  Serial.printf("BME280 at address 0x%02X failed to start", hexAddress);
}

// Getting data from BME280
tempC = bme.readTemperature(); //deg C
pressPA = bme.readPressure();  //pascals
humidRH = bme.readHumidity();  // %RH
```

Assignment: I^2C

- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

1. L07_02_BME280
   - Read BME280 data.
   - Convert to tempF and inHg.
   - Print to Serial.Monitor and the OLED display.
   - Use your NeoPixels to give a visiual indication of room conditions (temperature, pressure, and humidity).

More Display Integration

1. L07_04_Plotter (Extra Credit)
   - Plot temperature vs time on the SSD1306 display.
   - One data point every 5ms
   - Display temperature and humidity at the bottom of the display
   - Test using your finger for warmth, and frozen water bottle for cold
2. L07_05_Pong (Extra Credit)
   - Create a paddle that moves with the encoder
   - Create a ball in motion, including bouncing off walls and paddle.

Module 8 - Internet

The Internet

IP Addresses

- When a device joins the network, it is given an internet address.
  - static or dynamic
- IPv4 (32-bit) - 4.2 billion
- IPv6 (128-bit) - $340 * 10^{27}$ (quadrilliard)
- In Git Bash: ipconfig -all
- In Powershell: ipconfig /all
- In Terminal (MAC/Linux): ifconfig

MAC Address

A MAC Address is a unique 6-byte (48-bit) address that is usually permanently burned into a network interface card (NIC) and uniquely identifies the device on an Ethernet-based network. The uniqueness of MAC addresses is ensured by IEEE.

If you are creating your own MAC address, the 2's place bit of the first byte, the "locally administered bit" should be set. The 1's place bit, the "globally administered" bit must be off.

Therefore, xA-xx-xx-xx-xx-xx is valid, while x7-xx-xx-xx-xx-xx is not.

Finding MAC Address

```
SYSTEM_MODE(SEMI_AUTOMATIC)
byte mac[6];

void setup() {

  WiFi.on();
  WiFi.connect();
  while(WiFi.connecting()) {
    Serial.printf(".");
    delay(250);
  }
  Serial.printf("\nWaiting for IP Address\n");
  delay(1000);
  Serial.printf("Scan Particle for WiFi Information \n");
  Serial.printf("ip address: %s \n", WiFi.localIP().toString().c_str());
  WiFi.macAddress(mac);
  Serial.printf("mac: %02X:%02X:%02X:%02X:%02X:%02X \n", mac[0],mac[1],mac[2],mac[3],mac
      [4],mac[5]);
}
```

```
Serial monitor opened successfully:
.....................................
Waiting for IP Address
Scan Argon for WiFi Information
ip address: 10.0.0.25
mac: C8:2B:96:B5:30:88
```

Forcing Connection to Specific Network

In finding your IP address, you connected to DDCIOT (strongest signal). If there are multiple networks and we want to force connection to a specific network:

```
SYSTEM_MODE(MANUAL);

void setup() {
  Serial.begin(9600);
  waitFor(Serial.isConnected,15000);

  WiFi.on();
  WiFi.clearCredentials(); //prevent from connecting to DDCIOT
  WiFi.setCredentials("IoTNetwork");
  // If network requires a password
  // setCredentials(const ""NetworkName", "Password");

  WiFi.connect();
  while(WiFi.connecting()) {
    Serial.printf(".");
  }
  Serial.printf("\n\n");
}
```

Assignment: Wemo

- Schematic
- Fritzing diagram
- Wire your circuit
- Write the code

1. L08_01_HelloWemo
   - Use the wemo example in IoTClassroom_CNM library as a template.
   - Use a button to toggle Wemo on/off (one toggle per press)
2. L08_02_WemoTimer (EXTRA CREDIT)
   - Implement a method to select different Wemo (encoder, second button, etc.)
   - Create timer that turns off a Wemo 10 secs after you push "off" button without using delay().
3. L08_03_Wemo_Object (EXTRA CREDIT)
   - Copy wemo.h to wemoObj.h
   - Modify it to be use Class and Methods.
   - Modify your code to use a wemoObj object.

Phillips Hue API

Application Programming Interface: a set of functions and procedures allowing the creation of applications that access the features or data of an operating system, application, or other service.

SOAP vs REST

SOAP (WS-*)
SMTP
HTTP POST
MQ...
Endpoint URI
Application
SOAP

POX
RSS
JSON
...
HTTP GET
HTTP POST
HTTP PUT
HTTP DEL
Resource URI
Application
REST

HSV Colors

Assignment: L08_04_Hue

- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

1. Using the hue example in IoTClassroom_CNM library as a template, create code that:
   - has a button that turns on and off the Hue light at your pod,
   - uses the encoder to change the brightness of the Hue bulb,
   - has a second button for of cycling the Hue light through the colors of the rainbow.

Caution: sending commands to the Hue hub too quickly fills the buffer and leads to sluggish response. The hue.h library has been written to reject commands that match the previous command.

Midterm 1 - Smart Room Controller

Sprint Project Plan

Sprint Project Plan (Gantt)

Hot	Task Name	Feature Type	Story Points
	AGILE PROJECT		
	Sprints		
	Sprint 1		31
	~~Implement human verification program~~	~~Security~~	~~8~~
	~~Export reports of user and their assigned products~~	~~Maintenance~~	~~5~~
	Right click export	Maintenance	3
	Menu export		2
	Drag and drop file upload	**Maintenance**	**18**
	Design Interface	Maintenance	5
	Develop Interface	Maintenance	2
	Test Interface	Maintenance	5
	Bug 459.7	**Maintenance**	**4**
	Bug 459.8	**Maintenance**	**2**
	Sprint 2		13
	Single Sign On	Account Management	13
	System Integrations	Account Management	5
	Login interface	Account	3

IoT Portfolio

hackster.io

- Create a hackster.io account.
- Follow barashap and edward-ishman
- Join the CNM Ingenuity channel

IoT Portfolio Github

Create a new repository

Under Security, change visibility to Public

Printing IoT Flowerpot

It is important to change Support Placement to Touching Buildplate.

Midterm Project - Smart Room Controller

1. Determine functionality of your Smart Room Controller.
   - Use the components that we have learned over the last 3 weeks.
   - Get minimum requirements from the Instructor.
   - Sketch out the layout of your room controller in your notebook.
   - Develop a sprint gantt chart as your project plan
   - Draw flowcharts of the main functions you plan to implement.
   - Get feedback from at least 3 peers on your planned functionality.
2. Layout your circuitry in Fritzing along with a legible schematic.
3. Wire up your circuitry as if you're going to demo your controller for a perspective customer.
4. Code, debug, test.
5. Documentation and Demonstration:
   - Ensure all files are uploaded to GitHub with an appropriate README.md.
   - Upload your project to hackster.io.
   - Prepare a presentation/demonstration for the class on your controller.
   - Participate in class demonstrations (Friday morning - Week 4).

Smart Room Controller - Minimum Requirements

You are developing a Smart Room Controller prototype that you are going to pitch to a perspective investor.

1. Control all the Hue lights in the classroom
2. Control at least two Wemo outlets in the classroom
3. Display dynamic messages on the OLED display
4. Use at least three additional components (LEDs, buttons, NeoPixels, Encoders, BME280, Servo motor, etc.)
5. Device has at least two modes
   - Manual - user controls lights and outlets
   - Automatic - external source triggers response of lights and/or outlet(s)
6. 3D design and print at least one part (button cover, knob, logo, etc.)
7. A component made at FUSE - laser, wood, metal (case, stand, etc.)
8. Extra Credit: use a component that we haven't learned in class
9. Extra Extra Credit: create a custom bitmap for your display